Decentralized systems

Paradigm shift of urban sanitation

- **1st generation: removal of BOD**
  - 1960-1990 in developed countries, 1990-2000s in Korea
  - Construction of sewers and centralized wastewater treatment plants
  - Highly subsidized by federal and state agencies
  - Took about 30 yrs for BOD removal from 10% to ~90%

#1

#2

Paradigm shift of urban sanitation

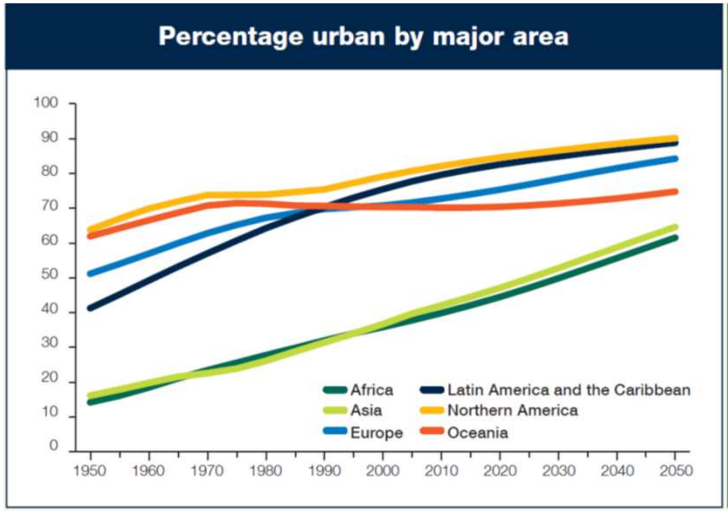
- **2^{nd} generation: improved effluent quality, including nutrient (N, P) removal**
  – Mainly to deal with eutrophication problems (algal bloom)

#3

- **3^{rd} generation??**

Current issues of urban sanitation

- **Rapid urbanization**
  - Rapid population growth
    (~20 billion in early 20c → ~70 billion current)
  - Most people dwell in urban areas
    (~20% in early 20c → ~50% current)
  - Rapid population growth
  - Limited budget to construct water infrastructure in developing countries
  - Projection of population in rapidly growing cities is challenging: overloading sewers
    - Frequent flooding of sewers
    - Permanently active CSOs (combined sewer overflow)
  - Water scarcity problems



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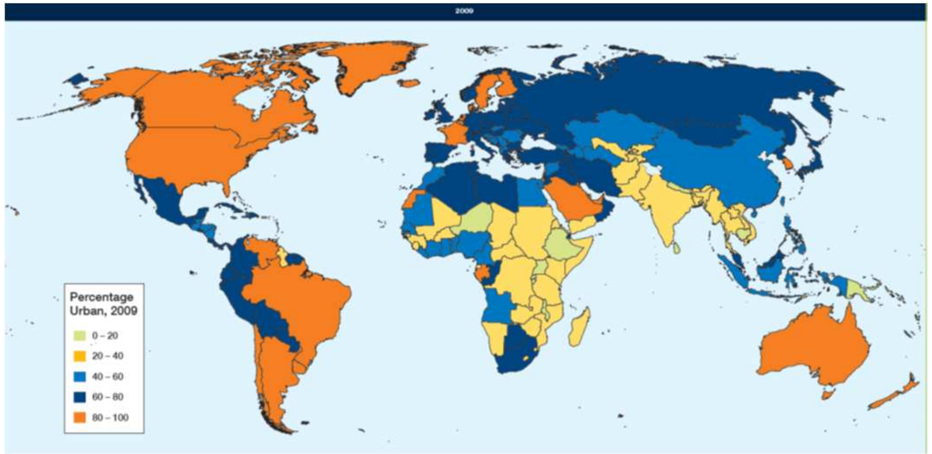


#4

Current issues of urban sanitation

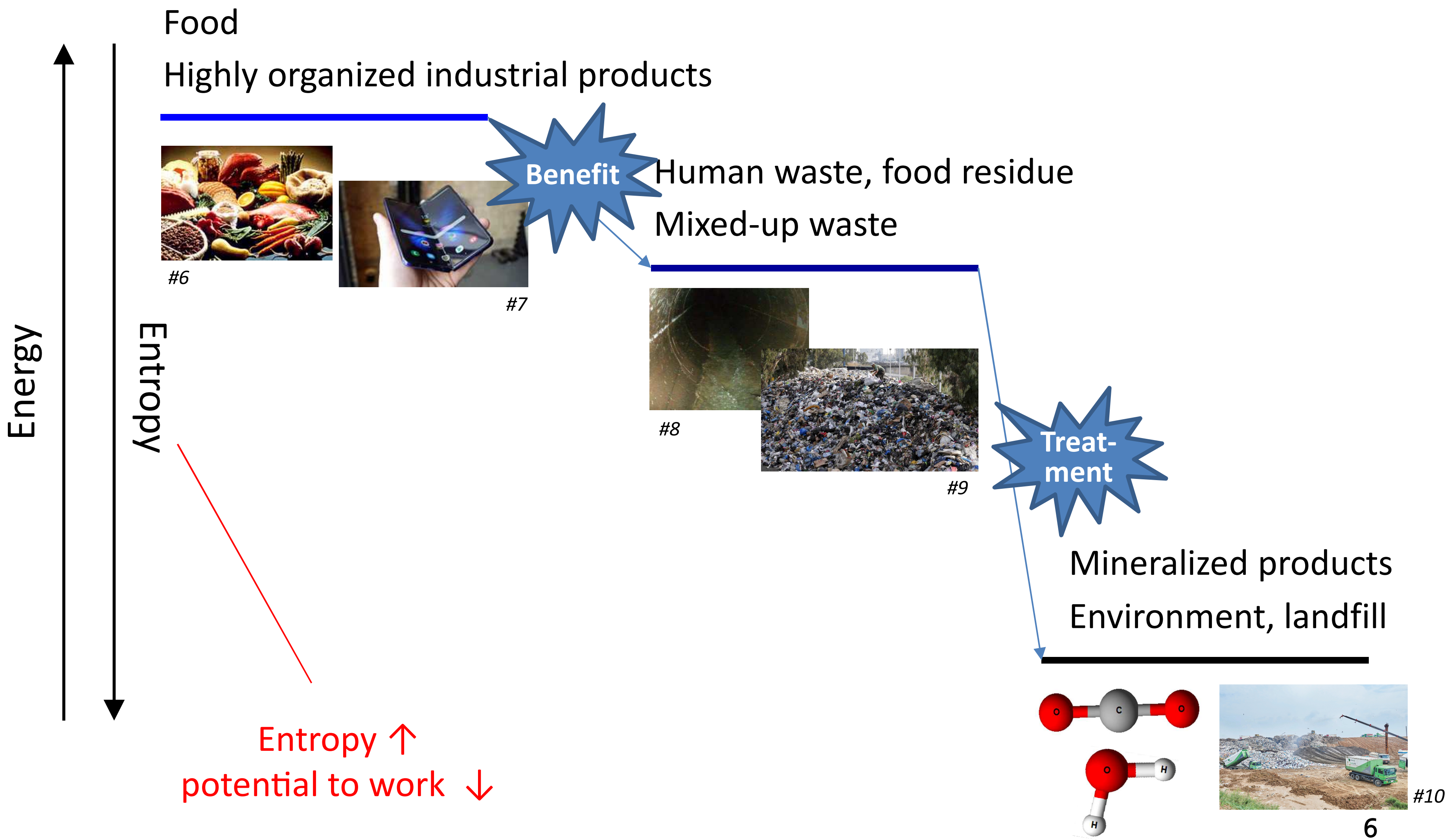
- **Sustainability issues**

  Need for

  - Low energy consuming (or energy-neutral, net energy-producing) facilities
  - Restore water cycle in urban areas
  - Facilities with lower carbon footprint

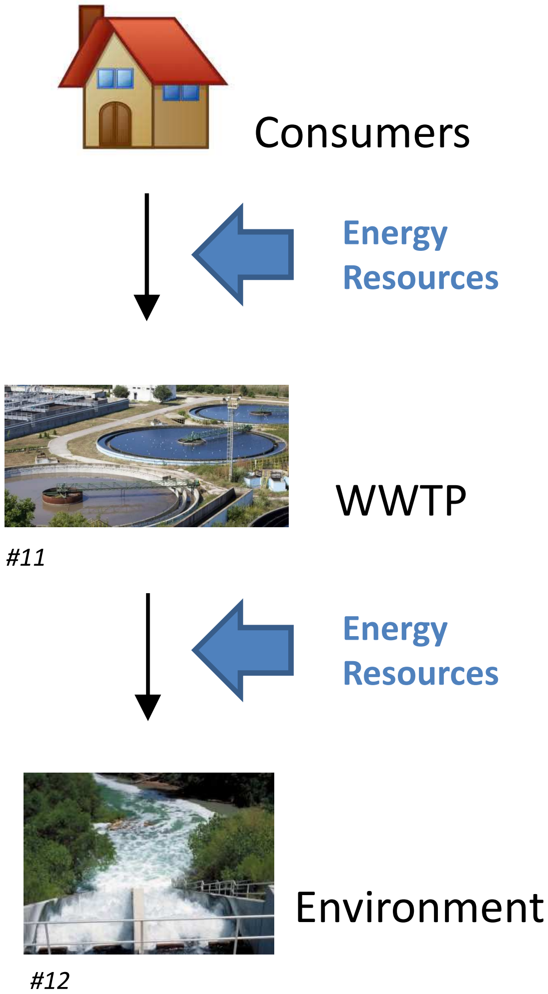
#5

Current urban metabolism



Current urban metabolism:

Wastewater drainage and treatment



- **Drainage (transport)**
  - Pipeline & pumping
  - Spend energy & resources to lower elevation (?!)
  - ~70% of total cost for WW management

- **Treatment**
  - Key process: aerobic biodegradation
  - Spend energy & resources to mineralize organics (?!)
  - >50% of total E for WW treatment spent for aeration

Wastewater: a resource?

- Wastewater = water + nutrients + reduced carbon (chemical energy) + heat

- Wastewater reuse
  - Effective solution in dry regions
    - Reliable water resource
    - Usually cheaper than saltwater desalination
  - Non-potable water reuse
    - Irrigation, toilet water, etc.
  - Potable water reuse: drinking
    - Direct potable reuse
    - Indirect potable reuse

#13

주식회사탄천환경
서울특별시 탄천물재생센터

#14

서남물재생센터

#15

Potable wastewater reuse

- For potable wastewater reuse, various advanced treatment techniques are applied

  ex1) secondary effluent → microfiltration/ultrafiltration → reverse osmosis → UV disinfection

  ex2) secondary effluent → coagulation/flocculation → settling → ammonia stripping → depth filtration → reverse osmosis (or activated carbon adsorption + chlorination)

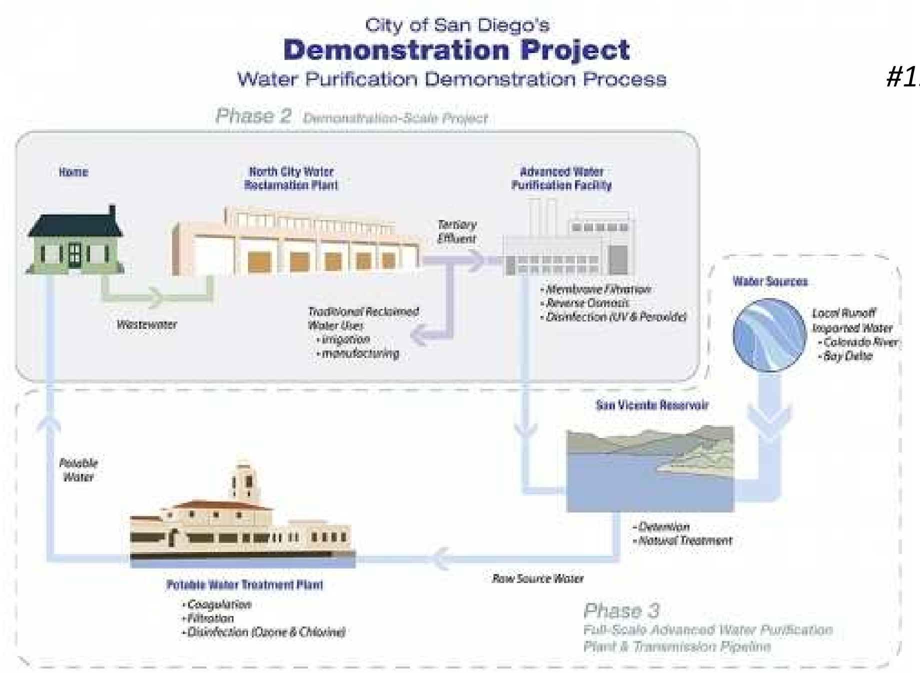
#16

#17

Potable wastewater reuse: indirect

#18

#19



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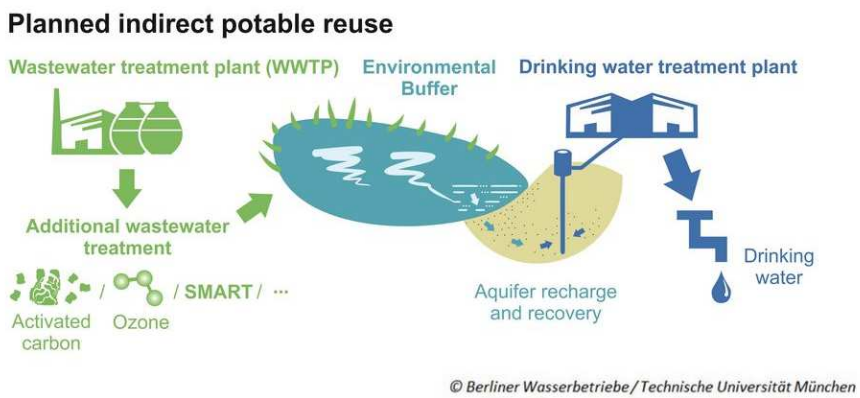


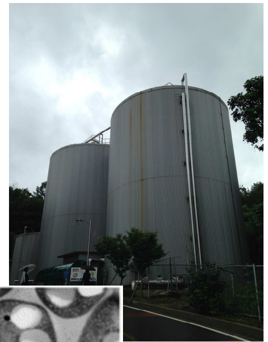
Resource recovery from wastewater

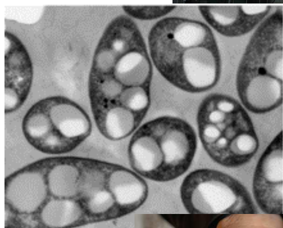
Table 1. Energy Characteristics of a Typical Domestic Wastewater

constituent	typical concentrations[a] (mg/L)	energy (kWh/m³) maximum potential from organic oxidation[b]	required to produce fertilizing elements[c]	thermal heat available for heat-pump extraction[d]
organics (COD)				
total	500			
refractory	180			
suspended	80	0.31		
dissolved	100	0.39		
biodegradable	320			
suspended	175	0.67		
dissolved	145	0.56		
nitrogen				
organic	15		0.29	
ammonia	25		0.48	
phosphorus	8		0.02	
water				7.0
totals		1.93	0.79	7.0

[a] After Tchobanoglous and Burton.[42] [b] Based upon a theoretical 3.86 kWh energy production/kg COD oxidized to CO_2 and H_2O.[3] [c] Based upon production energy of 19.3 kWh/kg N by Haber-Bosch Process and 2.11 kWh/kg P after Gellings and Parmenter.[6] [d] Energy associated with a 6 °C change in water temperature through heat extraction.

#21





#22

#23

- Recovery of reduced carbon: CH_4, bioethanol, bio-oil, bioplastics, …
- Recovery of other forms of energy: electricity, H_2, …
- Recovery of nutrients: fertilizer (ex: struvite), soil amendments (ex: stabilized sludge), …
- Recovery of low-temperature heat using heat pumps


18.5 km
#24, #25, #26, #27
서울시청
부천시청
광명시청
김포국제공항
행주대교
북로
한국항공대학교
망원산
은평구
상명대학교
국민대학교
평창계곡
정릉
동덕여자대학교
북서울꿈의숲
성북구
고려대학교
성균관대학교
인왕산
서대문구
경복궁
종묘
흥인지문
동대문구
연세대학교
서울월드컵경기장
월드컵공원
가양대교
강서구
염창
봉제산
양화대교
서강대
서강대교
마포대교
원효대교
서울역
남산
동국대학교
한양대학교
성동구
용산구
용산역
국립중앙박물관
한남대교
한남
강남구
국회의사당
영등포구
63시티
한강대교
동작구
동작대교
반포대교
영등포역
신길재정비촉진지구
양천구
구로구
신월
오류
중앙대학교
국립서울현충원
잠원
반포
서초
예술의전당
보라매공원
금천구
광명스피돔
광명종합운동장
부천옥길공공주택지구
김포신곡6도시개발구역
노오지
계양
서운일반산업단지
서운
부천
중동
송내
장수
인천대공원
시흥
과천주암뉴스테이지구

#28

Fresh urine, ~8800 mg N/L

x100 dilution

WWTP influent, 40~70 mg N/L

#11

Source separation requires decentralization

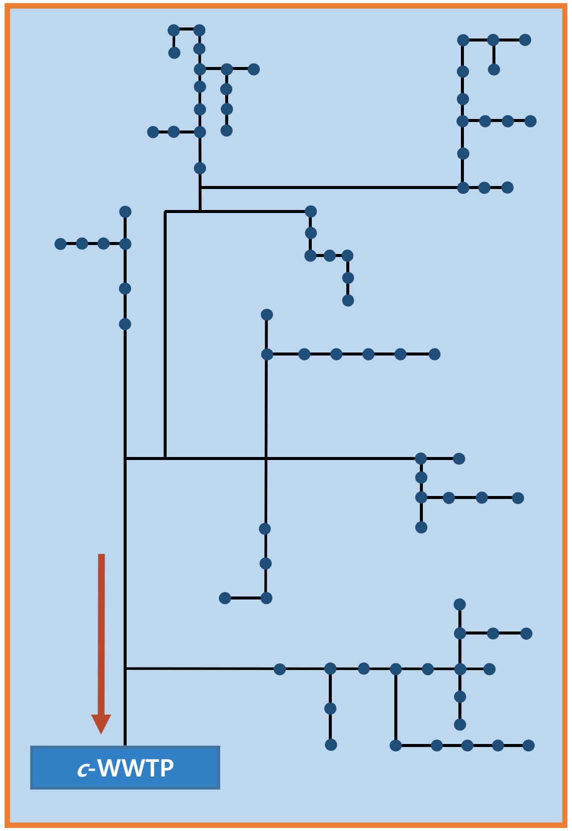
#29

vs

#9

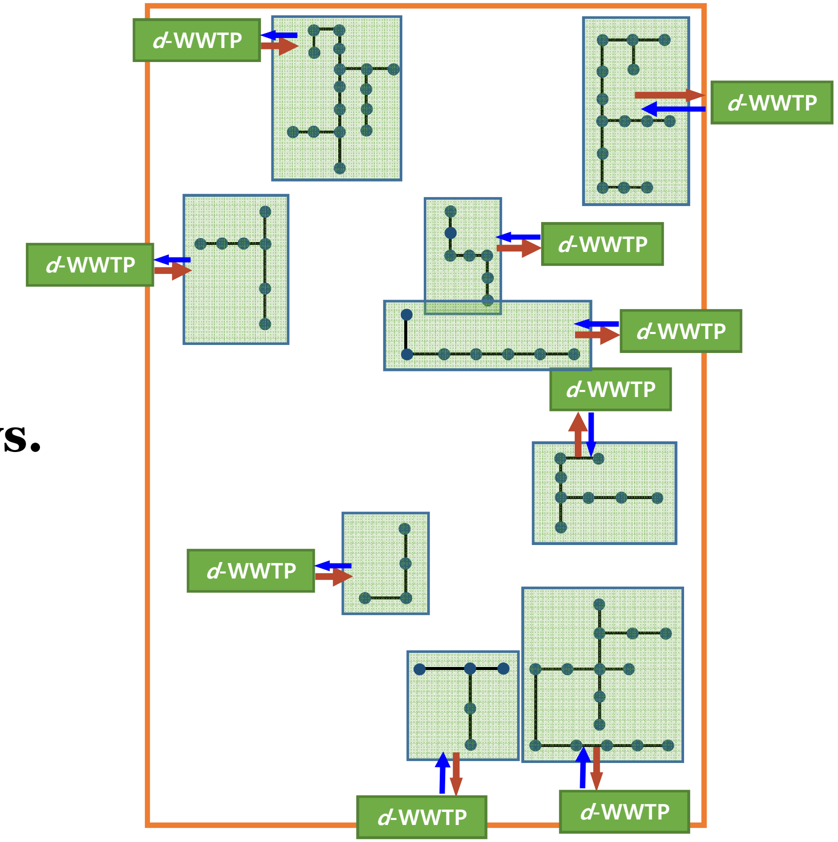
Fully centralized vs. fully decentralized

Fully centralized

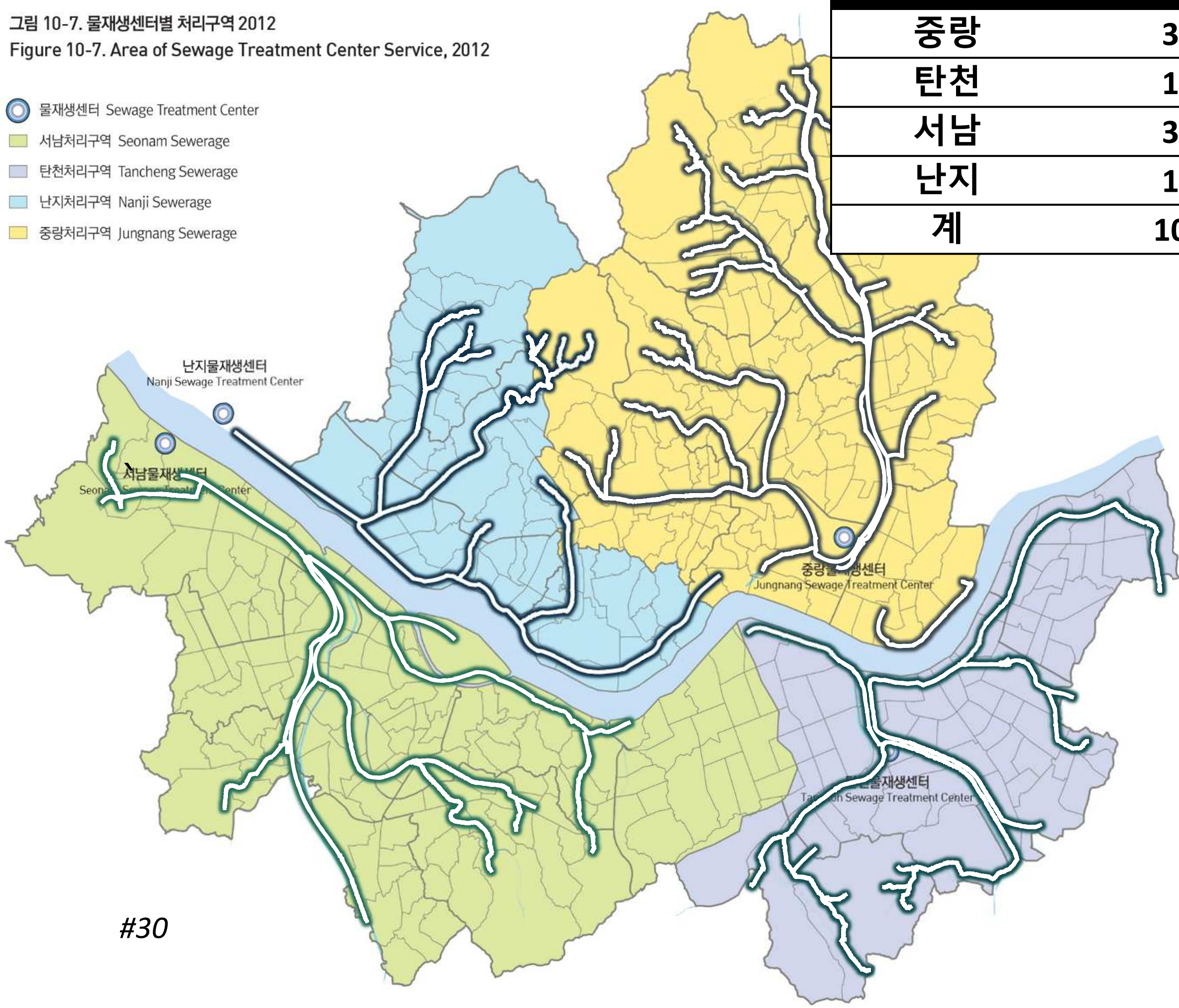


vs.

Fully decentralized



Fully centralized process



처리구역	관로연장(km)	처리시설용량(백만 m³/일)
중랑	3,601	1.71
탄천	1,896	1.10
서남	3,366	2.00
난지	1,839	1.00
계	10,728	5.81

#30

Fully decentralized process

#31

- New Monte Rosa, the Switzerland; at the top of Monte Rosa ski resort
- Project by ETH Zurick

- Designed as an energy-independent building
- Electricity consumption for wastewater treatment↑ than designed by increased number of visitors
- At peak season, wastewater was drained untreated / transported outside by helicopters

Decentralization: issues

- Challenge of acceptance
- Challenge of transport
- Challenge of developing treatment processes

#32

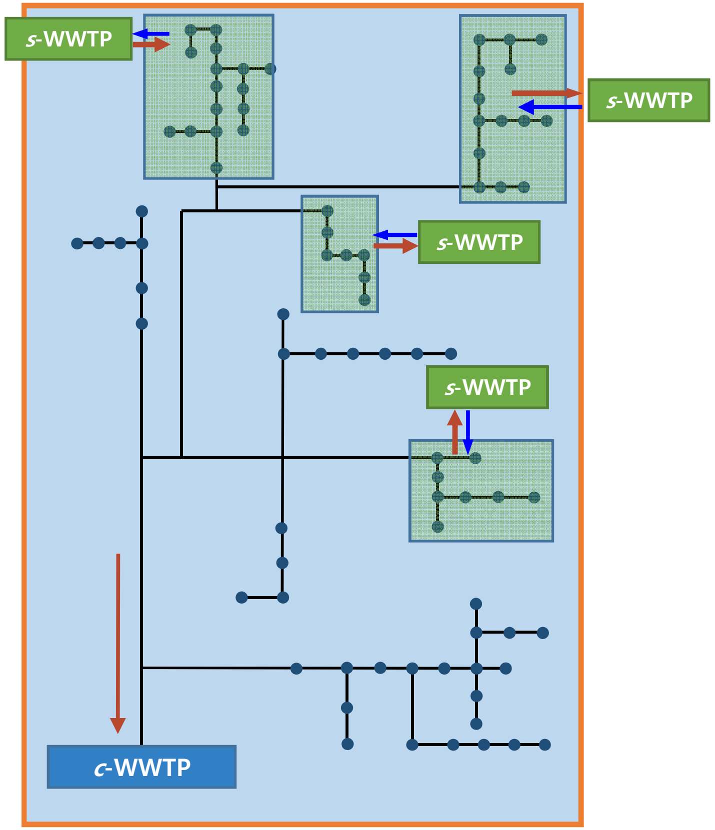
Table 10.1 Characteristic differences between decentralized and centralized wastewater treatment systems (see also Olsson 2013).

Topic	Properties of decentralized systems	Properties of centralized systems
Waste flow and load	Highly variable, subject to individual events	Variable, but individual events not apparent
Rainwater	Hardly an effect	May define hydraulic design load
Waste composition	Rather homogenous conditions between plants Rather concentrated waste	Different for each plant, subject to individual industries. Rather dilute wastewater.
Frequency of attendance	Irregular, long intervals	Daily to permanent
Cost of intervention	Large	Relatively low
Relative cost of sensors	High	Rather low
Calibration of sensors	Very low frequency and relatively very costly	Costly, but rather frequent
Sensor properties	Must be rugged and reliable, accuracy is of secondary importance, very infrequent maintenance	Must be sensitive, accurate and reliable but may require frequent maintenance
Data transmittance and control system	Due to on-going expansion of the number of systems, elements must be based on an adaptive grid	Typically fixed for one technological cycle
Control software	Highly standardized, but due to application in large numbers also highly optimized	May rely on modular design but adaptation to a specific plant typically required
Required process standardization	Very high, only standardized equipment can be produced in large numbers	Individual plants are typically designed as prototypes
Transport of pollutants and residues	Local extraction of concentrated residues and separate transport	Transported in sewers and extracted in the form of concentrated sludge
Handling of residues	May be centralized. An intermediate form may be transported to a central handling station	Typically occurs at the plant. Only small plants connect to larger ones

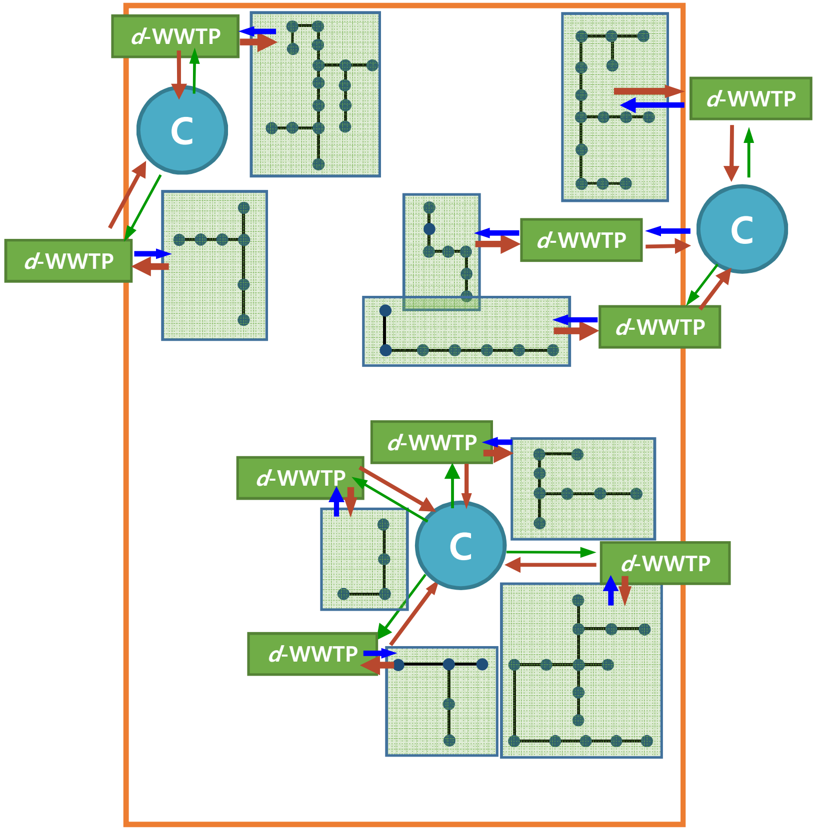
#33

Need for optimization, flexibility

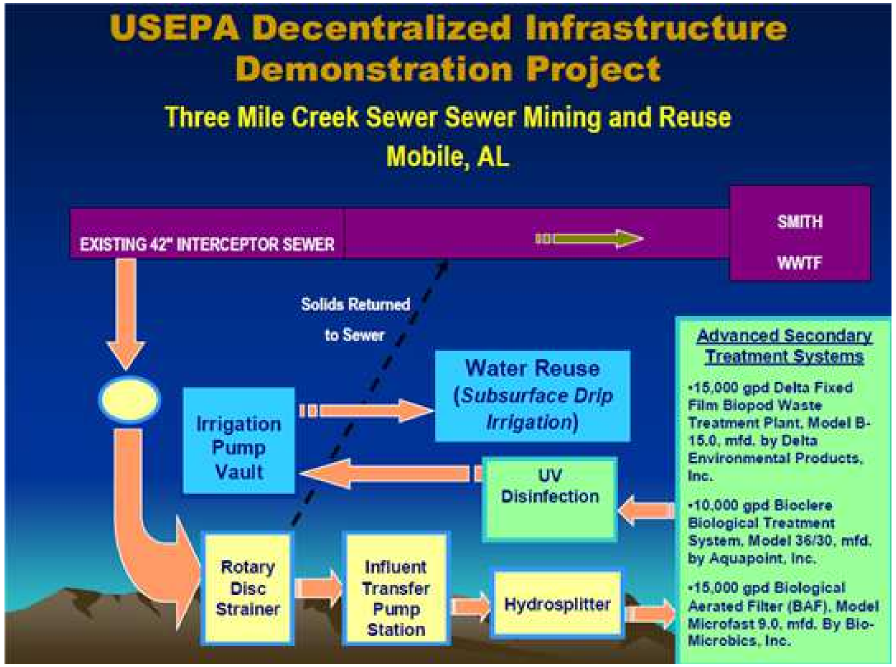
Hybrid
(cent.+satellite)



Clustered
(clustering for control, recovery, etc.)



Potential starting point: sewer mining



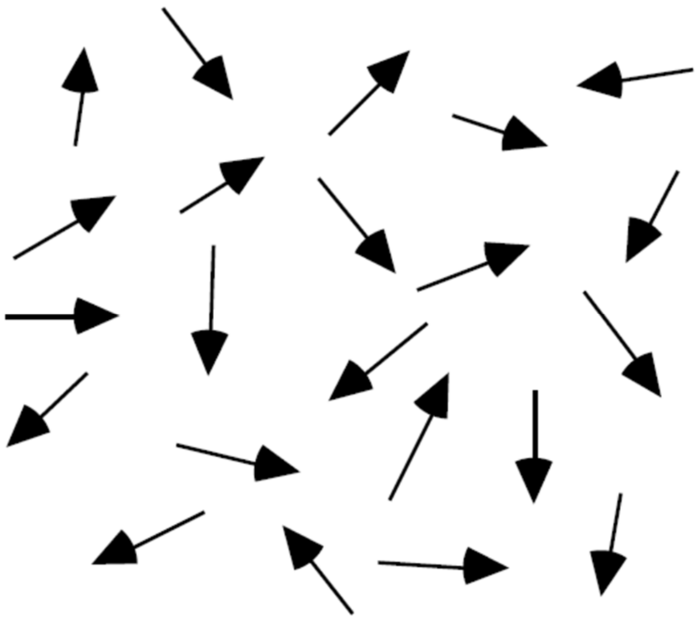
#34

- City of Mobile, Alabama, US
- A portion of wastewater was extracted from a sewer pipe, treated at a decentralized facility & reused as irrigation water for parks

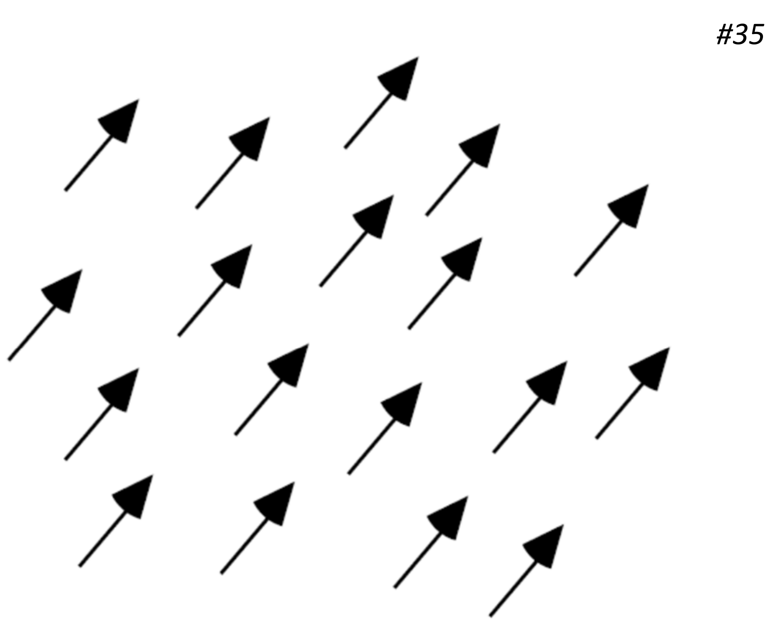
- Water extraction rate: 150 m^3/day
- Decentralized process: rotary screen (pretreatment) → biological treatment (attached growth) → UV disinfection → subsurface irrigation
- Irrigation water quality: BOD ~10 mg/L, T-P 5~15 mg/L, NO_3-N 4~14 mg N/L

Towards ideality: self-organization?

- "A process where some form of overall order arises from local interactions between parts of an initially disordered system"



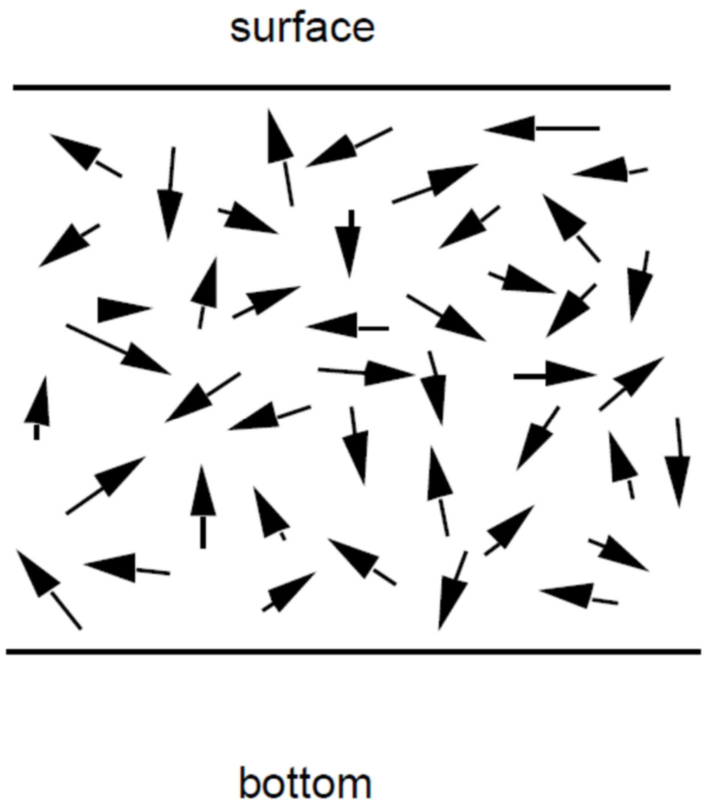
Disordered arrangement of "spins"



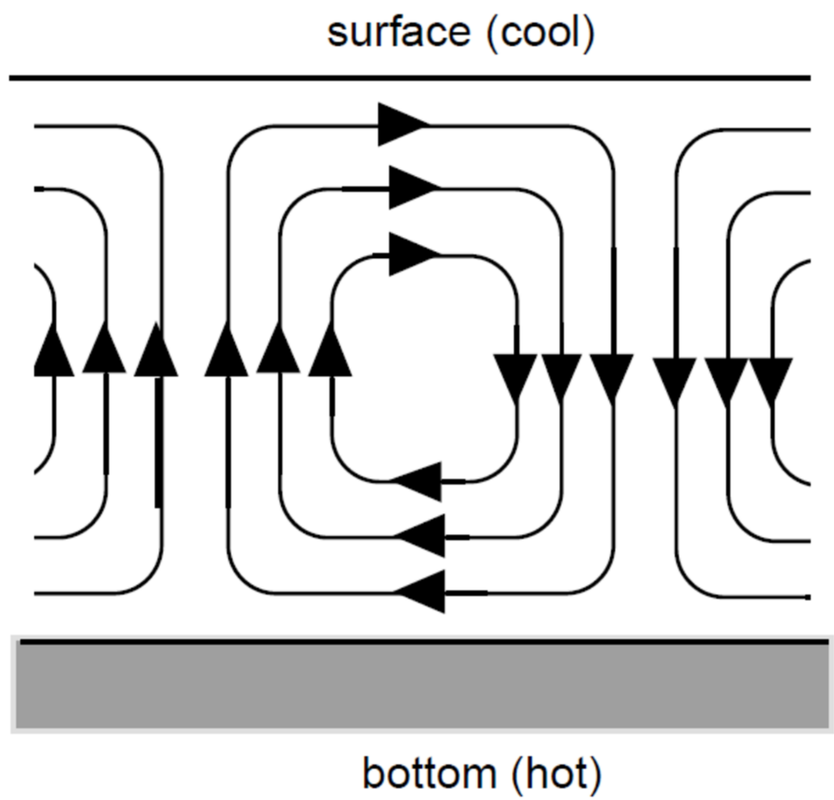
Ordered arrangement of "spins": **magnet**

Self-organization

#36



Random movement of water molecules



Ordered movement of water molecules: **“Bénard roll”**

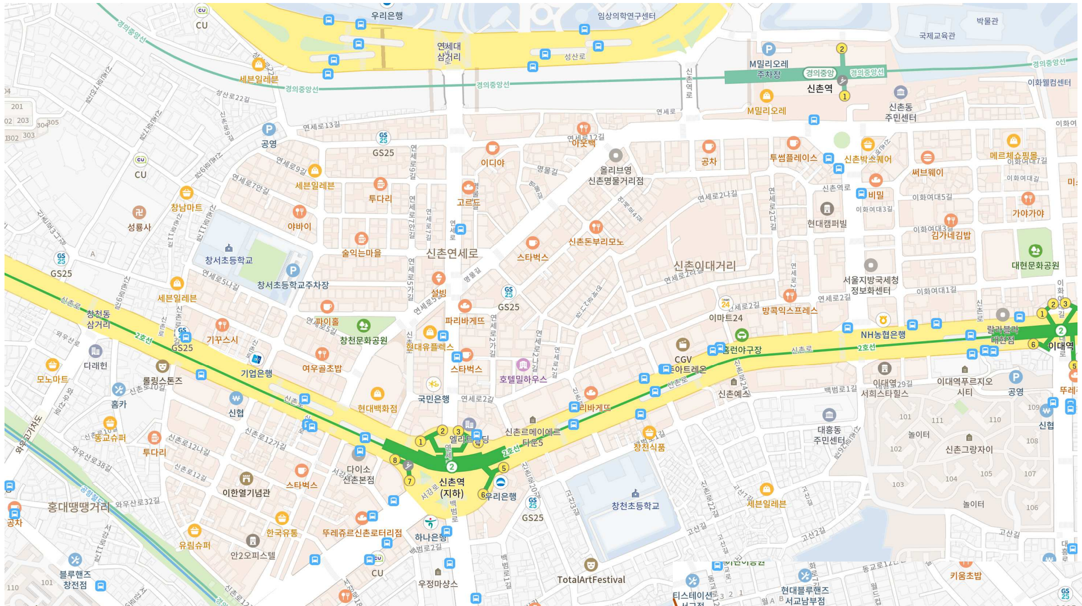
Characteristics of self-organizing systems

- Global order from local interactions
- Distributed control
- Robustness, resilience
- Non-linearity and feedback
- Emergence
- Bifurcation
- Far-from-equilibrium dynamics

(Heylighen, 1999) *#36*

#37

Self-organization in urban infrastructure?



#24

For the new paradigm

- Thick differently but comprehensively: a “smartphone approach”

“A smart phone is not a downsized telephone, TV, photo camera, computer, CD player, and so on but a new device which fulfills its tasks on the basis of entirely new technology and with considerably less material and at less cost than all these gadgets together.”

#38

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